OCCURRENCE OF PLANETARY SYSTEMS IN THE UNIVERSE

by

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ABSTRACT

Occurrence of planetary systems in the universe is discussed in light of what has been learned from a study of stellar rotation. It has been found that planetary systems are expected to be associated with most main-sequence stars. However, the Jovian-like planets around the early-type stars may not be as massive as Jupiter and their terrestrial-like planets are likely located beyond 10 A.U. from the central star. Also, the mass and the size of our own planetary system appear to be normal among those associated with solar-type stars.

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The only planetary system that we have observed is our own solar system. Consequently, it is highly speculative to talk about planetary systems in general as the present author trys to do in this paper. However, if we are interested in life outside the solar system, perhaps the nature and frequently occurrence of planetary systems in space is one of the most important problems facing those who are talking about interstellar communications.[1] Apart from this consideration the existence of planetary systems other than our own is itself a fascinating subject whose interest is not limited to the astronomer alone.

In the past when we talked about the possible population of planetary systems in space, we usually linked them with population of binary systems, because they share the common property of possessing large angular momentum.[2,3] Such a linkage between planetary systems and binary systems overlooks however the important fact that planets in our own planetary system are revolving around the sun in nearly circular orbits while the eccentricities of binary orbits can vary from 0 to nearly one, a fact which has recently been emphasized by Kumar.[4] For this reason the planets that Brown[5] has discussed recently are not bona fide planets in a planetary system but are rather individual planets - like objects floating in space singly or in groups. These objects which are not members of a system that has the characteristics

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of our own planetary system will be excluded from our present discussion. Hence, for planetary systems themselves, the present paper may represent the first attempt to discuss quantitatively their nature and frequency distribution in space. Naturally the result derived here should be regarded as tentative. By presenting this result however the author trys to focus this problem and invites further discussions on this interesting subject.

Most scientists now agree that our planetary system must have evolved from a rotating disk of gases and dust. This explains the nearly circular orbits of planets. Therefore in order to find the frequency of planetary systems in space, we should investigate how a rotating disk of gases and dust may be formed around a star. This brings us to the problem of rotating stars.

Struve[6] discovered that main-sequence stars of early spectral types (O, B, A) show statistically high rotation. But rotation stops quite abruptly at F5. Few main-sequence stars later than F5 that are not components of binaries rotate with equatorial velocities that are undetectable with the present means of observation.

It has therefore been speculated[7] that the missing angular momentum of late-type main-sequence stars may be absorbed in the planetary systems that are associated with these stars. For we see no reason why angular momentum of stellar material should have a discontinuity at F5. Questions can then be raised: Why do the early-type stars keep their angular momentum in stars themselves, while the late-type stars keep their angular momentum in planetary systems? The answer obviously lies in the braking mechanism of stellar rotation. The braking mechanism transfers angular momentum outward from stars to the surrounding medium. When the surrounding medium acquired the angular momentum, it collapses into a disk from which a planetary system may be formed. In 1959 however we didn't have an effective braking mechanism for transporting angular momentum outward. Consequently, no further study was made along this line of reasoning.

In the intervening years we have witnessed many successful theories which all require that the primeval sun and stars must have strong magnetic activities. These theories have been summarized elsewhere[8]. As a result of these theories, we now have a good magnetic braking mechanism of stellar rotation.[9,10] All these recent developments induce the present author to undertake once more a study of the relationship between stellar rotation and planetary system formation.

In making the study, we have assumed that three components of the angular momentum per unit stellar material is distributed according to the Gaussian error curve. This assumption is based on the result of statistical studies of observational data by Struve and the present writer.[11] By examining the observed rotational behavior of stars in different spectral types we can estimate not only the degrees of braking that stars have suffered but also the original distribution of angular momentum per unit mass of pre-stellar condensations.[12] The most probable value for the angular momentum per unit mass of pre-stellar condensations is 3×10^{17} cm^2/sec. Main-sequence stars of spectral types O, B and A have been slightly braked. Those of spectral types G, K and M have been braked nearly to rest.

The braking of stellar rotation simply means a process of transporting angular momentum outward. Hence, the angular momentum is absorbed in the surrounding medium that may be the remnant of star formation. Hence, the missing angular momentum in the star must be stored in the surrounding medium. After acquiring the angular momentum the latter will inevitably collapse into a rotating gaseous disk from which a planetary system will emerge as a result of local condensations -- a topic that has been extensively discussed in connection with the formation of our own solar system.

We have discussed the transport of angular momentum from the star to the surrounding medium. A question may be raised: Is there always a medium surrounding the newly formed star? In the first place most investigators on the origin of the solar system assumed a solar nebula as a remnant of formation of the sun. Similarly, we may postulate that a similar remnant is there in any newly formed star. However, a more forceful reason for the existence of such a medium is the fact that rotation of main-sequence stars has been braked. For without such a medium in the immediate neighborhood the star cannot dissipate its angular momentum effectively even by magnetic means. Most particles that have been ejected along magnetic lines of force from the star will eventually return to the star without losing their angular momentum, if nothing on their way absorbs the momentum. This situation may be compared with the geomagnetic field. High energy charged particles spiral back and forth along the magnetic lines of force in the Van Allen belt but they do not dissipate the angular momentum of the earth's axial rotation.

Since we have determined from empirical data the distribution of angular momentum per unit mass of pre-stellar condensations as well as the degree of braking of stellar rotation in each spectral type, we can immediately find the distribution of total angular momenta in various planetary systems. To simplify the description of a planetary system, we may define the "equivalent planet" as a fictitious planet that possesses the total mass and total angular momentum of the entire planetary system. Hence, the dynamical property of a planetary system may be roughly (though not completely) defined by the mass and its location of the equivalent planet. In this way the distribution of varieties of planetary systems may be represented by the distribution of points on the m versus a diagram where m and a represent respectively the mass and the orbital radius of the equivalent planet of each system.

For stars of the solar and later spectral types, all angular momentum that was previously contained in the pre-stellar condensations is now stored in the planetary system. Accordingly, we can plot the distribution of equivalent planets in the m versus a diagram. For stars with mass equal to 1 solar mass, the most probable place that the equivalent planets may be located is near the central line in Figure 1. The chance of finding them decreases as we go away from these most probable locations. In 50% of cases, the equivalent planets should lie between two lines marked by 50%. Similarly, in 98% of cases, the equivalent planets should lie between two lines marked by 98%. Therefore, it is interesting to note that the equivalent planet corresponding to our own planetary system lies slightly below the lower 50% line and is within the expected region.

At this point we may inquire what will be the effect on the equivalent planet of our own system as a result of mass dissipation before the planets were formed from the gaseous disk. If the angular momentum were strictly conserved during the mass dissipation stage, the angular momentum of our system would be slightly less than the most probable value. But during the mass dissipation stage some angular momentum may have been lost, though unlikely in any large amount because only those particles with small angular momenta can easily escape. Consequently, we may conclude that our planetary system is a normal one for the solar type stars. In other words, most solar-type stars are expected, according to the present theory, to possess similar planetary systems.

It may be mentioned that for stars less massive than the sun, the corresponding m versus a diagram for equivalent planets can be obtained by shifting the entire diagram vertically by an amount of $\frac{1}{2} \log (M/M_\odot)$, where M is the mass of star. Hence, statistically, the planets may be either smaller than or nearer to the central star than do the planets in the solar system. If so, the chance of life emergence in

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Figure 1 - The general behavior of planetary systems associated with the solar-type stars according to the present theory. It shows the probable location where the mass and the orbital radius of the equivalent planets will be found, the equivalent planet being defined as a planet which possesses the total mass as well as the total angular momentum of the entire planetary system associated with each solar-type star.

those planets may be reduced. For small planets will have a difficulty to maintain the necessary atmosphere for supporting life while planets near to the central star will suffer a large tidal force whose synchronizing effect on rotation and revolution may cause extreme temperatures in two hemispheres of the planets that are not congenial to life.

For the early-type stars the braking of rotation is not complete. Hence, we can estimate from the observed behavior of stellar rotation the maximum amount of braking. From the latter we can calculate the maximum amount of angular momentum of the planetary systems that are associated with these stars. A similar m versus a diagram like Figure 1 can thereby be drawn. For a B5 star we have found that the upper limit of equivalent planets may be represented by a line nearly coinciding with the lower 50% line in Figure 1. The most probable positions for the equivalent planets are near this upper limit. From this study we expect that main-sequence early type stars can also possess planetary systems. However, because of high temperatures of these stars, Jovian-like planets associated with them may be farther away from the central star than are the Major planets of our own system from the sun. This is predicted on the assumption that it needs low temperatures to incorporate hydrogen and helium into condensations that are to become Jovian-like planets.[5] Hence, the planet-like objects that may be floating in interstellar space but do not belong to a planetary system are Jovian-like, while terrestrial-like planets perhaps exist only in the planetary systems that are revolving around stars.

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